8 Earthquakes and Earth's Interior

Big idea

Dynamic Earth

Q: What is an earthquake?

Thousands of homes were destroyed in the town of Ofunato, Iwate Prefecture, Japan after a major earthquake triggered a tsunami on March 26, 2011.

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.a, ES.1.c, ES.1.d, ES.2.c, ES.7.a, ES.7.b.
See lessons for details.

INQUIRY
TRY IT!

HOW CAN BUILDINGS BE MADE EARTHQUAKE-SAFE?

Procedure

1. Construct a model of a one-story brick building using two thin pieces of cardboard as the floor and roof. Use sugar cubes as bricks and frosting, or two-sided tape, to hold the bricks together.
2. Construct a second building. Make this building a two-story structure.
3. To test how well your buildings stand up to a simulated earthquake, place each building on a table or desk. Then gently shake the edge of the table. Record your observations.
4. Construct another one-story building using pieces of window screen as reinforcement. Spread a thin layer of frosting on the inside walls and carefully attach the screens. Use extra frosting to reinforce the inside corners.
5. Repeat Step 3 with the reinforced building. Record your observations.

Think About It

1. **Observe** What happened to each building during the simulated earthquakes?
2. **Use Models** Compare the amount of earthquake damage in the three model buildings.

8.1 What Is an Earthquake?

ES.7 The student will investigate and understand geologic processes including plate tectonics. Key concepts include **a.** geologic processes and their resulting features; and **b.** tectonic processes.

Key Questions

What is a fault?

What is the cause of earthquakes?

Vocabulary

- earthquake • fault • focus
- seismic waves • epicenter
- elastic rebound • aftershock

Reading Strategy

Build Vocabulary Copy the table below. Then as you read the section, write a definition for each vocabulary term in your own words.

Vocabulary	Definition
earthquake	a. ___?___
fault	b. ___?___
focus	c. ___?___
seismic waves	d. ___?___

THOUSANDS OF earthquakes occur around the world every day. Fortunately, most of these earthquakes are so small that only sensitive instruments can detect them. About 75 strong earthquakes occur each year, and many of them occur in remote regions. Occasionally, a strong earthquake occurs near a major population center. As you will learn, such events are among the most destructive natural forces on Earth.

Earthquakes

An **earthquake** is the vibration of Earth produced by the rapid release of energy within the lithosphere. Earthquakes are caused by slippage along a break in the lithosphere, called a **fault.** **Faults are fractures in Earth where movement has occurred.**

Focus and Epicenter The point within Earth where an earthquake starts is called the **focus.** The focus of an earthquake is located along a fault beneath the surface. The energy released by the earthquake travels in all directions from the focus in the form of **seismic waves.** These waves are similar to the waves produced when a stone is dropped into a calm pond. Just as the impact of the stone causes waves to travel outward in all directions from the point of impact, seismic waves travel outward in all directions from the focus.

When you see a news report about an earthquake, the reporter always mentions the place on Earth's surface where the earthquake was centered. The **epicenter** is the location on the surface directly above the focus, as shown in **Figure 1.**

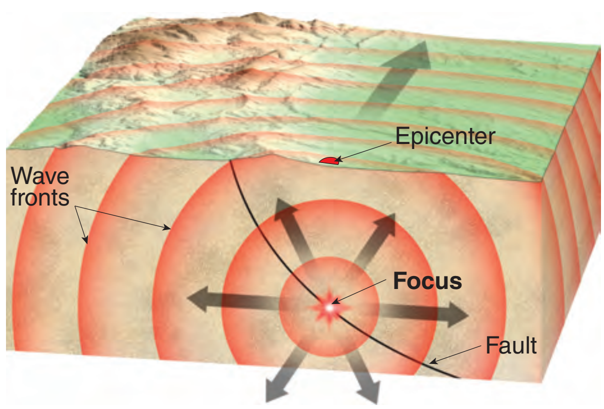


FIGURE 1 **Earthquake** The focus of an earthquake is the place within Earth where the earthquake starts. The surface location directly above the focus is called the epicenter. **Predict** *Where do you think the damage from an earthquake is usually greatest?*

Faults and Change to Earth's Surface The movement that occurs along faults during earthquakes is a major factor in changing Earth's surface. The land along a fault can shift p to tens of meters in just one earthquake. Over time, this movement can push up coastlines, mountains, and plateaus.

The crust can move vertically or horizontally as a result of fault movements. If the crust moves up vertically, geologists say that it has been uplifted. Vertical movement can produce a sharp-edged ridge called a *fault scarp*. If the crust moves horizontally, geologists say it has been *offset* or displaced. **Figure 2** shows the effect of horizontal displacement in a spring onion field. In the middle of the photograph, you can see where offset caused a shift in he crop rows.

FIGURE 2 Offset An earthquake caused the offset in this spring onion field. The offset occurred as a result of the 1995 Kobe earthquake in western Japan.

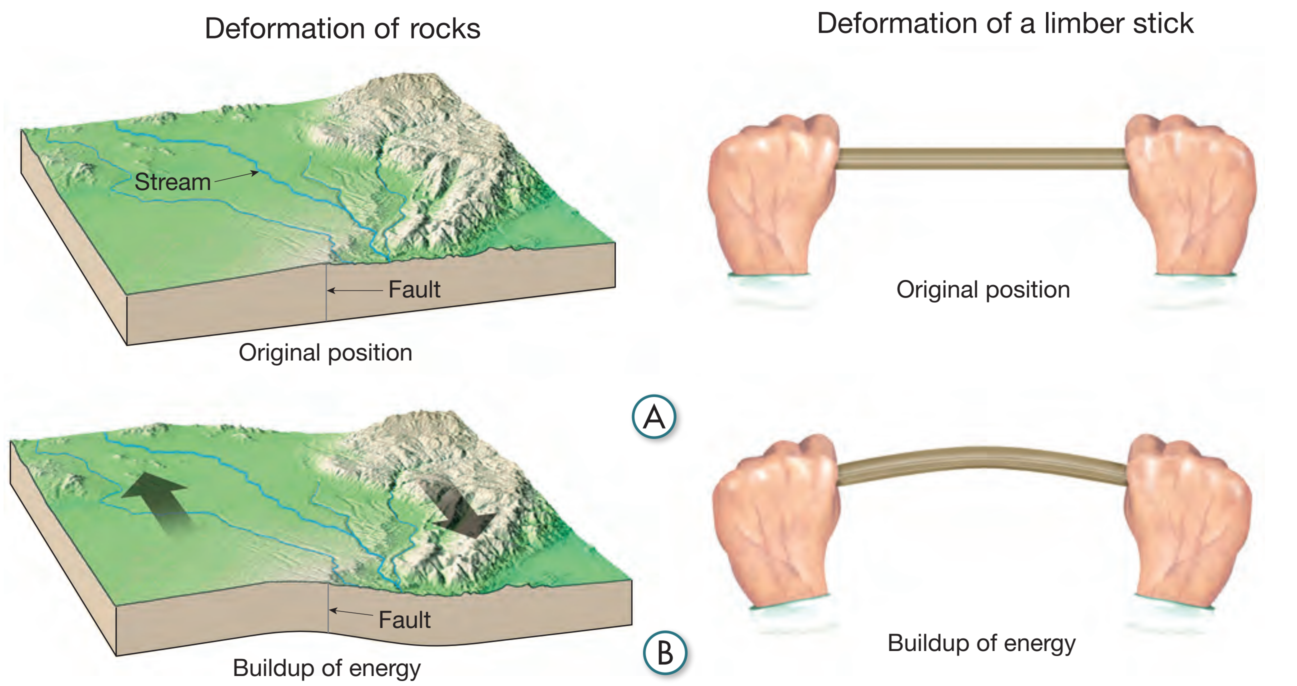
The San Andreas Fault The San Andreas fault system in California is one of the most studied in the world. The fault extends about 1300 kilometers through the state and into the Pacific Ocean. Studies have shown that displacement has often occurred along segments of the fault that are 100 to 200 kilometers long. Each fault segment behaves a bit differently than the others. Some parts of the fault show a slow, gradual movement known as *fault creep*. Other segments regularly slip and produce small earthquakes. However, some segments stay locked for hundreds of years before they break and cause great earthquakes.

One great earthquake on the San Andreas fault was the 1906 San Francisco earthquake. During this earthquake, the land on the western side of the fault moved as much as 4.7 meters relative to the land on the eastern side of the fault.

☑ **Reading Checkpoint** *What fault was involved in the 1906 San Francisco earthquake?*

The Cause of Earthquakes

Before the great San Francisco earthquake, scientists did not understand what causes earthquakes. Measurements and studies after the 1906 earthquake led to the development of a hypothesis that explains how earthquakes occur. **According to the elastic rebound hypothesis, most earthquakes are produced by the rapid release of energy stored in rock that has been subjected to great forces. When the strength of the rock is exceeded, it suddenly breaks, releasing some of its stored energy as seismic waves.** Earthquakes occur when the frictional forces on the fault surfaces are overcome.



VISUAL SUMMARY

ELASTIC REBOUND

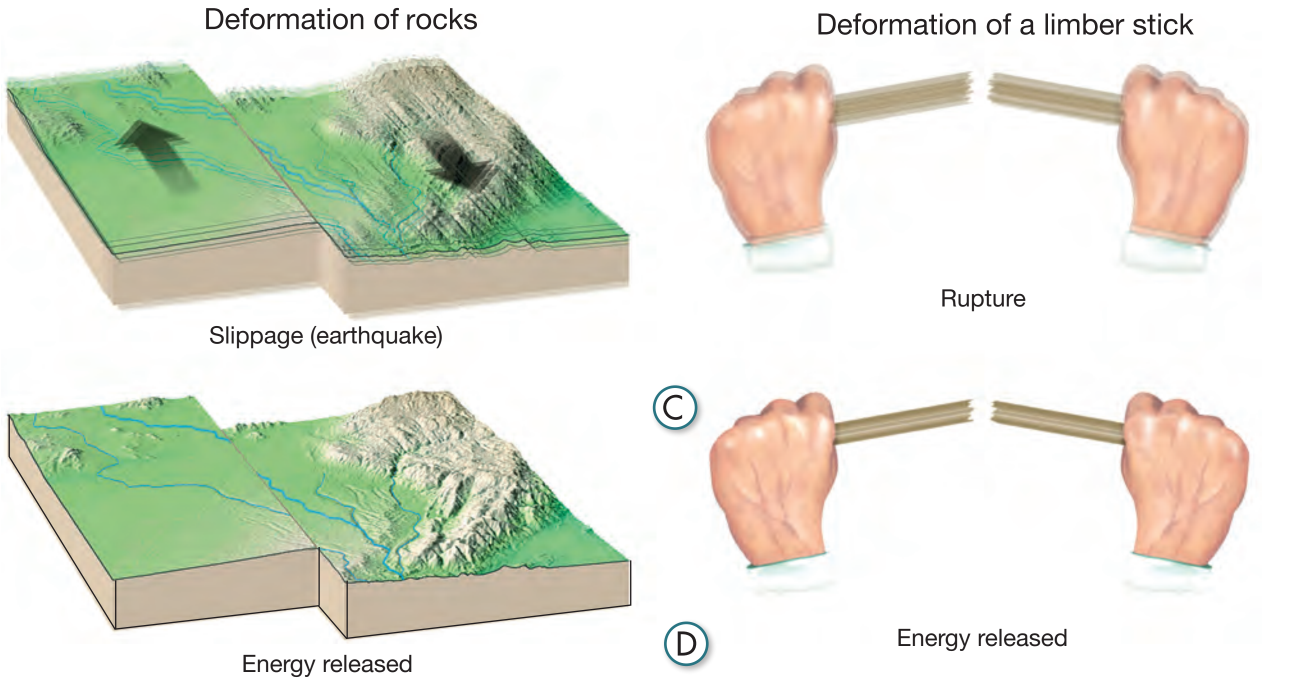
FIGURE 3 **A** Rock does not change shape until enough force is applied. **B** Rock bends as it is stressed, storing elastic potential energy. **C** Once the rock is strained beyond its breaking point, it ruptures. **D** Stored energy is released in the form of seismic waves. **Predict** ***How do you think the temperature of rock would affect its ability to bend or break?***

Deformation of Rocks Forces inside Earth slowly deform the rock that makes up Earth's crust, causing the rock to change its shape, or bend. As rocks bend, they store elastic energy, just as a wooden stick does when it is bent. *Elastic energy* is the energy associated with objects that can be stretched or compressed. Elastic energy is stored when you stretch a rubber band or compress a spring.

Elastic Rebound What happens to the elastic energy stored in rock? Again, think about bending a wooden stick. If you let go of one end, the stick springs back to its original shape. At the same time, the stick's stored elastic energy is released. But if you continue to apply force to the stick, it eventually snaps, also releasing the stored energy.

Something similar to bending a stick happens in the rock along a fault. Stored elastic energy builds up as the rock is deformed as shown in **Figure 3B.** Then, suddenly, the resistance caused by internal friction that holds the rocks together is overcome. The rocks slip at their weakest point—the focus of an earthquake. This movement exerts force farther along the fault, where additional slippage occurs until most of the elastic energy is released as shown in **Figures 3C** and **3D.** The tendency for the deformed rock along a fault to spring back after an earthquake is called **elastic rebound.** Elastic rebound is similar to what happens when you release a stretched rubber band. But most of the energy released as a result of elastic rebound causes the movement along a fault that takes place during an earthquake.

Reading Checkpoint *What is elastic rebound?*



Aftershocks and Foreshocks Even a strong earthquake such as the 1906 San Francisco earthquake usually does not release all the elastic energy stored in the rock along a fault. Aftershocks and foreshocks also release some of a fault's stored elastic energy. An **aftershock** is an earthquake that occurs sometime soon after a major earthquake. Aftershocks may occur hours or even weeks after the major earthquake. Although usually much weaker than the main earthquake, an aftershock can still damage structures already weakened by the main quake. Small earthquakes called *foreshocks* sometimes come before a major earthquake. Foreshocks can happen days or even years before the major quake.

8.1 Assessment

Review Key Concepts

1. What is a fault?
2. Describe the cause of earthquakes.
3. What is an earthquake?
4. What are two ways in which deformation affects rock?
5. What are foreshocks and aftershocks?

Think Critically

6. **Draw Conclusions** How are an earthquake's fault, focus, and epicenter related?
7. **Explain** What is meant by elastic rebound?
8. **Make Judgments** Why do most earthquakes cause little damage and loss of life?

MATH PRACTICE

9. **Calculate** In 25 years, how much movement will result from a fault that slowly slips 1.5 centimeters per year?

8.2 Measuring Earthquakes

Key Questions

What are the two categories of seismic waves?

How are seismic waves recorded?

How is the size of an earthquake measured?

How is an earthquake epicenter located?

Vocabulary

- P wave
- S wave
- surface wave
- seismograph
- seismogram
- moment magnitude

Reading Strategy

Outline As you read, make an outline of the important ideas in this section. Use the orange headings as the main topics and the blue headings as subtopics.

Measuring Earthquakes

I. Seismic Waves
  A. P Waves
  B. ___?___
  C. ___?___
II. ___?___

IN 2003, a powerful earthquake shook the Alaska wilderness south of Fairbanks along the Denali fault. The earthquake was so strong that it rippled the water in ponds and lakes thousands of kilometers away in Louisiana and Texas. What carries the energy released in an earthquake over such vast distances? The answer is seismic waves.

After an earthquake, Earth vibrates like a bell that has been struck with a hammer. Seismic waves transmit the energy of these vibrations from particle to particle through the materials that make up the lithosphere, mantle, and core.

Seismic Waves

Earthquakes produce two main types of seismic waves—body waves and surface waves. These seismic waves differ in their type of wave motion, their behavior as they travel through Earth, and their speed. Body waves travel through Earth's interior to the surface. Surface waves only travel at the surface. There are two types of body waves: P waves and S waves.

P Waves

P waves compress, or push, and expand, or pull particles in the direction the waves travel. P waves are also known as *compressional waves*. The motion of P waves can be illustrated by attaching one end of a spring toy to a wall and pushing and pulling on the other end as shown in **Figure 4A.** P waves cause material to compress and then spring back once the force is removed. Since solids, liquids, and gases all have the ability to alternatively compress and expand in response to a force, P waves can travel through all three states of matter. The back-and-forth motion of P waves causes the ground to buckle and fracture as shown in **Figure 4B.**

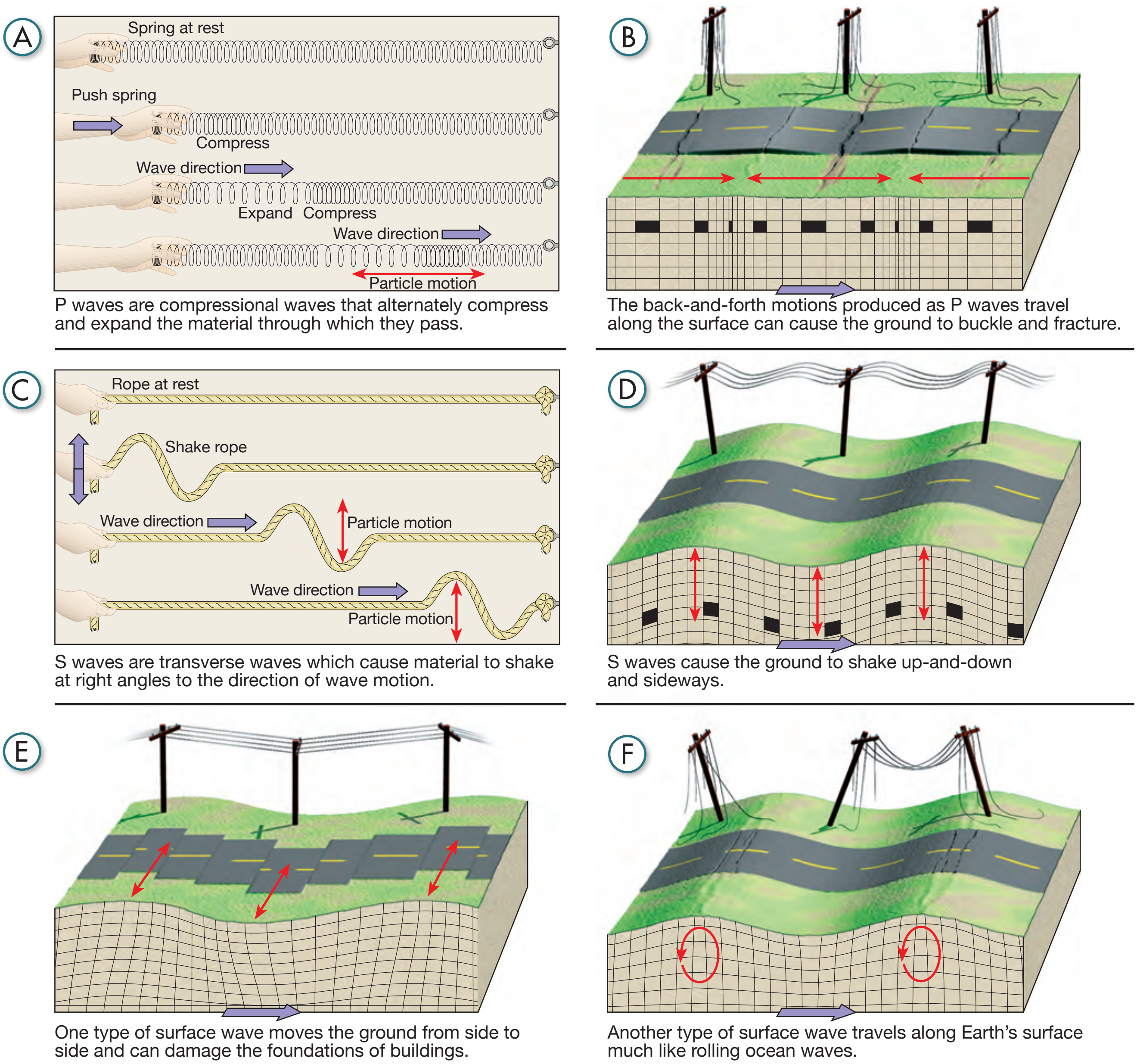
S Waves

S waves shake particles at right angles to the direction that the waves travel. S waves are also called *transverse waves*. Their motion can be illustrated by attaching one end of a rope to a wall and shaking the other end up-and-down, as shown in **Figure 4C.** S waves temporarily change the shape of the material that transmits them. Since liquids and gases will not return to their shape once a force is removed, they will not transmit S waves. Solids, on the other hand, do resist changes in their shape, so they will transmit S waves. As **Figure 4D** shows, S waves cause the ground to shake sideways and up-and-down. S waves travel more slowly than P waves.

VISUAL SUMMARY

SEISMIC WAVES

FIGURE 4 **A** P waves are made in a spring toy by pushing and pulling on one end while the other end is fixed to a wall. **B** The ground moves back-and-forth as a result of P waves. **C** S waves are made in a rope by moving one end up-and-down while the other end is fixed to a wall. **D** The ground moves up-and-down and sideways as a result of S waves. **E** Surface waves can move the ground from side to side, and **F** in an elliptical motion.



A: P waves are compressional waves that alternately compress and expand the material through which they pass.

B: The back-and-forth motions produced as P waves travel along the surface can cause the ground to buckle and fracture.

C: S waves are transverse waves which cause material to shake at right angles to the direction of wave motion.

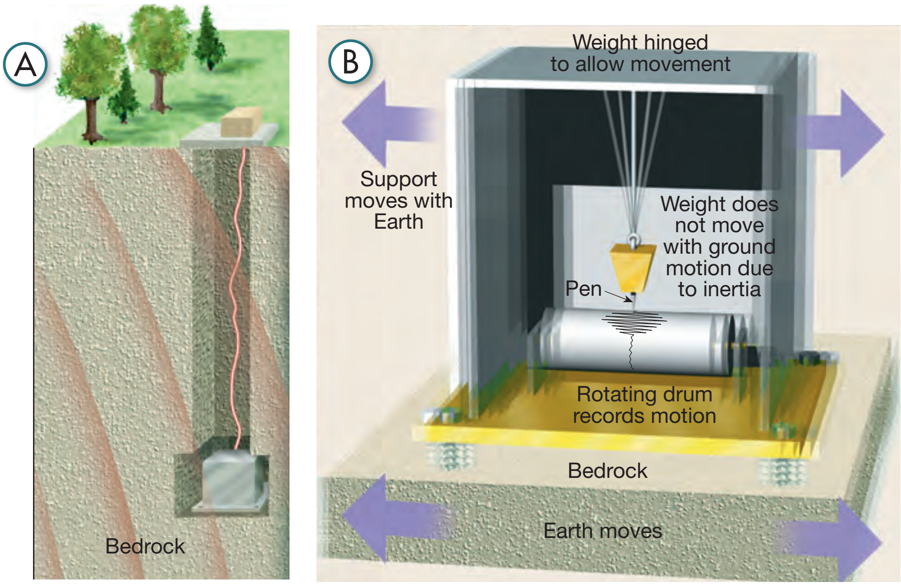
D: S waves cause the ground to shake up-and-down and sideways.

E: One type of surface wave moves the ground from side to side and can damage the foundations of buildings.

F: Another type of surface wave travels along Earth's surface much like rolling ocean waves.

Surface Waves When body waves reach the surface, they produce **surface waves.** Surface waves travel more slowly than body waves. As shown in **Figures 4E** and **4F,** surface waves can move the ground up-and-down as well as side to side. Surface waves are usually much larger than body waves. As a result, surface waves are the most destructive seismic waves.

FIGURE 5 Seismograph
A A seismograph is attached to bedrock so that it can record ground motion. **B** One type of seismograph uses a pen and a rotating drum to record Earth's movement relative to a nearly stationary weight.



Recording Seismic Waves

An instrument that records seismic waves is called a seismograph. The word seismograph comes from the Greek words *seismos,* meaning "shake" and *graph,* meaning "write."

As shown in **Figure 5B,** a seismograph can consist of a weight suspended from a support attached to bedrock. When seismic waves reach the seismograph, the inertia of the weight keeps it almost stationary while Earth and the support vibrate. Because the weight stays almost motionless, it provides a reference point for measuring the amount of ground movement caused by seismic waves. In older seismographs a pen records the movement of Earth relative to the stationary weight on a rotating drum. Modern seismographs amplify and record ground motion electronically.

A seismograph produces a time record of ground motion during an earthquake called a **seismogram.** A seismogram shows all three types of seismic waves. The stronger the earthquake, the larger the waves on the seismogram. By reading a typical seismogram, as shown in **Figure 6,** you can see that P waves arrive first at the seismograph, followed by S waves, and then surface waves.

ACTIVE ART

For: Seismic Waves activity
Visit: PearsonSchool.com
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Reading Checkpoint *What is a seismogram?*

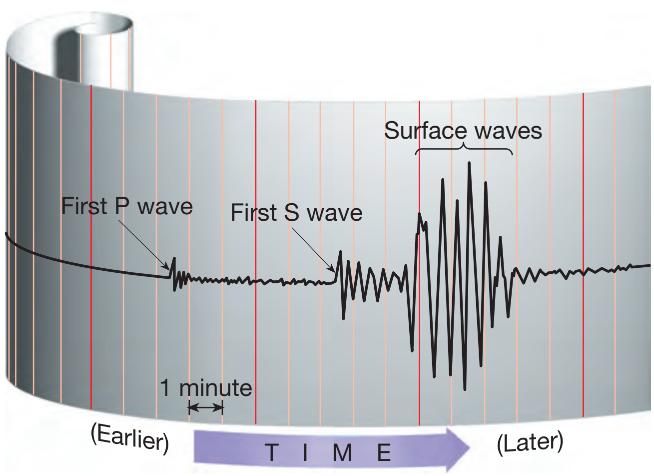


FIGURE 6 Typical Seismogram
The first wave to arrive is the P wave, followed later by S waves. The last waves recorded are the surface waves.
Measure ***What is the time interval in minutes between the arrival of the first P wave and the arrival of the first S wave?***

Measuring Earthquakes

Intensity is a measure of the amount of earthquake shaking at a given location based on the amount of damage. *Magnitude* (abbreviated as "M") is a measure of the size of seismic waves or the amount of energy released at the source of the earthquake. **The Richter scale and the moment magnitude scale measure earthquake magnitude. The Modified Mercalli scale is based on earthquake intensity.**

Richter Scale A familiar but outdated scale for measuring the magnitude of earthquakes is the Richter scale. The Richter scale is based on the height of the largest seismic wave (P, S, or surface wave) recorded on a seismogram. A tenfold increase in wave height equals an increase of 1 on the magnitude scale. For example, the amount of ground shaking for a M5.0 earthquake is 10 times greater than the shaking produced by an earthquake of M4.0 on the Richter scale.

Seismic waves weaken as the distance between the earthquake focus and the seismograph increases. The Richter scale is only useful for small, shallow earthquakes within about 500 kilometers of the epicenter. News reports often use the Richter scale in reporting earthquake magnitudes. Scientists, however, no longer use it routinely.

Moment Magnitude Scientists today use a more precise means of measuring earthquakes. It is called the moment magnitude scale. The **moment magnitude** is derived from the amount of displacement that occurs along a fault. Moment magnitude is the most widely used measurement for earthquakes because it is the only magnitude scale that estimates the energy released by earthquakes. The moment magnitude is calculated using several factors in addition to seismographic data. These factors include the average amount of movement along the fault, the area of the surface break, and the strength of the broken rock. Together these factors provide a measure of how much energy rock can store before it suddenly slips and releases this energy during an earthquake.

Table 1 describes the incidence of earthquakes of different magnitudes. During the last 100 years, there were only a few earthquakes with magnitudes of 9.0 or greater. These rare but extremely powerful earthquakes all occurred on faults located around or near the Pacific basin.

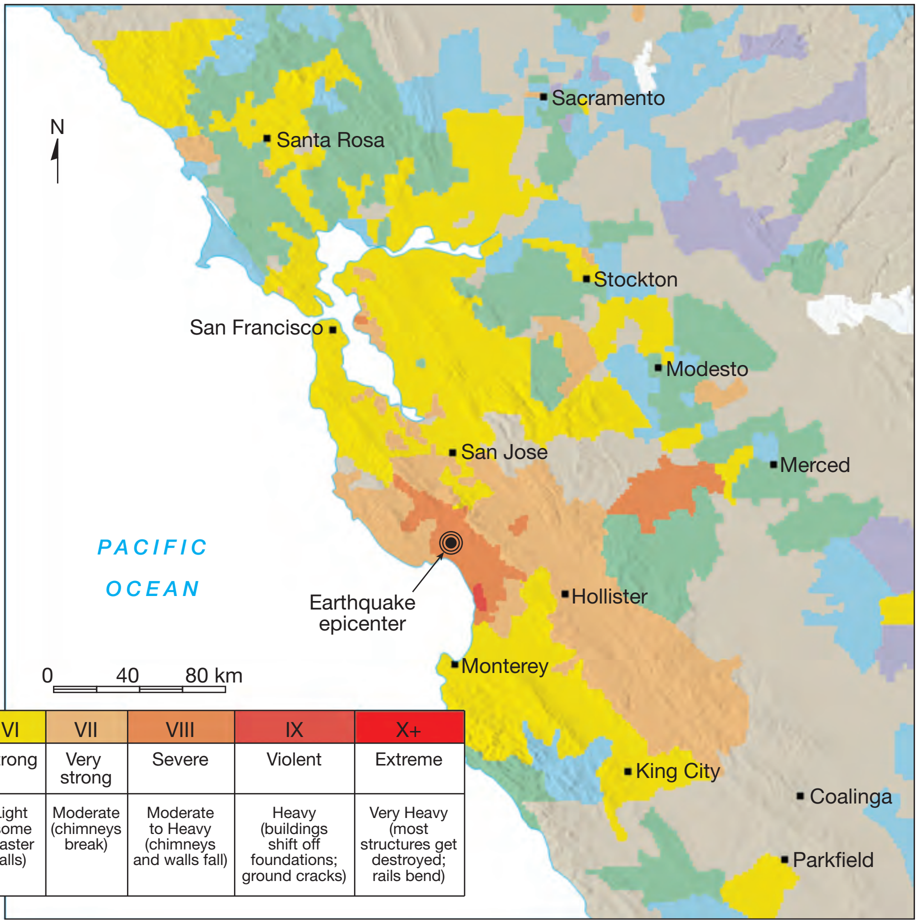
Reading Checkpoint *What is moment magnitude?*

Table 1 Earthquake Magnitudes

Moment Magnitudes	Effects Near Epicenter	Number per Year
< 2.0	Generally not felt	Not available
2.0–2.9	Potentially perceptible	≈1,300,000
3.0–3.9	Rarely felt	≈130,000
4.0–4.9	Can be strongly felt	≈13,000
5.0–5.9	Can be damaging shocks	1319
6.0–6.9	Destructive in built-up areas	134
7.0–7.9	Major earthquakes; serious damage	15
8.0 and above	Great earthquakes; destroy communities near epicenter	1

Source: United States Geological Survey

FIGURE 7 Modified Mercalli Scale
The magnitude-6.9 Loma Prieta earthquake struck the northern San Andreas fault near Santa Cruz, California, in 1989.



Modified Mercalli Scale

Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Damage	none	none	none	Very light (some windows break)	Light (some plaster falls)	Moderate (chimneys break)	Moderate to Heavy (chimneys and walls fall)	Heavy (buildings shift off foundations; ground cracks)	Very Heavy (most structures get destroyed; rails bend)

Modified Mercalli Scale Another scale used to rate earthquakes is the Modified Mercalli scale. This scale rates an earthquake's intensity in terms of the earthquake's effects at different locations. The scale has up to 12 steps, expressed as Roman numerals. An earthquake that can be barely felt is rated I. An earthquake that causes near total destruction is rated XII. The same earthquake can receive different Mercalli scale ratings at different locations. For example, an earthquake might be rated VIII (severe damage) near the epicenter, but only IV (light damage) 50 kilometers away. The map in **Figure 7** uses the Mercalli scale to show areas affected by different levels of shaking from a major California earthquake.

Locating an Earthquake

The difference in speeds of P and S waves provides a way to locate the epicenter. The movement of these two types of seismic waves is like a race between two cars. The winning car is faster than the losing car. The P wave always wins the race, arriving ahead of the S wave. The longer the race, the greater the difference will be between the arrival times of the P and S waves at the fi ish line (the seismic station). The greater the interval between the arrival of the fi st P wave and the fi st S wave, the greater the distance to the earthquake epicenter. The difference in arrival times of P waves and S waves can be shown on a travel-time graph like the one in **Figure 8A.**

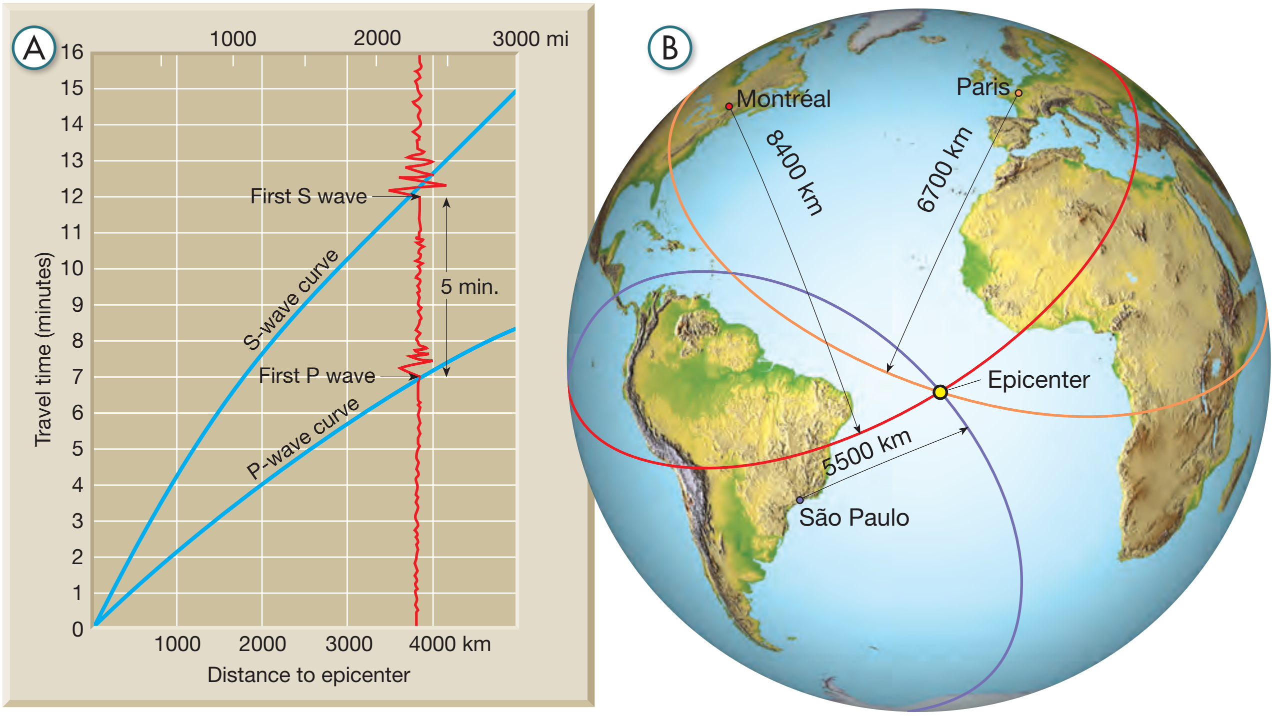


FIGURE 8 Locating an Earthquake A The difference in arrival times of the first P wave and the first S wave on the travel-time graph is 5 minutes. So the epicenter is roughly 3800 kilometers away.

B Once scientists determine the distance from three or more seismic stations to the epicenter, they can draw circles to determine the location of the epicenter. The epicenter is the point where the circles intersect.

Read Graphs *What is the difference in arrival times between P waves and S waves for a seismic station that is 2000 km from an epicenter?*

You can use a travel-time graph, data from seismograms at three or more locations, and a globe to determine an earthquake's epicenter. First you use the travel-time graph to determine the distance from each seismic station to the epicenter. Then, on a globe showing each seismic station, as in **Figure 8B**, you draw circles at the correct scale for the distance from each station to the epicenter. The radius of each circle equals the distance to the epicenter from that station. The point where all three circles intersect is the epicenter.

8.2 Assessment

Review Key Concepts

1. List the two categories of seismic waves.
2. Describe how scientists detect and record seismic waves.
3. Describe the three different ways to measure the size of an earthquake.
4. Briefly describe how the epicenter of an earthquake is located.

Think Critically

5. **Compare and Contrast** Describe the differences in speed and mode of travel between P waves and S waves.
6. **Apply Concepts** How does a seismograph measure an earthquake?
7. **Draw Conclusions** Describe what would occur in an earthquake with a moment magnitude of 6.0.

8.3 Earthquake Hazards

Key Questions

What are the major hazards produced by earthquakes?

How can earthquake damage be reduced?

Vocabulary

- liquefaction
- tsunami
- seismic gap

Reading Strategy

Monitor Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. List two things you expect to learn. After reading, state what you learned about each item you listed.

What I Expect To Learn	What I Learned
a. ___?___	b. ___?___
c. ___?___	d. ___?___

THE PRINCE WILLIAM SOUND earthquake that struck Alaska in 1964 was the most violent earthquake to jar North America in the 20th century. The earthquake was felt throughout Alaska. It had a moment magnitude of 9.2 and lasted 3 to 4 minutes. The quake left 131 people dead and thousands homeless. The state's economy was also badly damaged because the quake affected major ports and towns. You can use the table on the next page to compare the magnitude of the Prince William Sound earthquake to other major earthquakes that have occurred since 1900.

Causes of Earthquake Damage

An earthquake as powerful as the 1964 Alaska earthquake can cause catastrophic damage. But even less powerful earthquakes also pose serious hazards. **Earthquake-related hazards include seismic shaking, liquefaction, landslides and mudflows, and tsunamis.**

Seismic Shaking The ground vibrations caused by seismic waves, called seismic shaking, are the most obvious earthquake hazard. Seismic waves interact to jolt and twist structures. Buildings made of unreinforced brick may collapse. Wood-frame buildings may remain intact, but still can be jolted off heir foundations.

Seismic shaking is generally strongest close to an epicenter. Yet strong seismic shaking can occur in areas of loose soil or filled land relatively far from an epicenter. The filled soil magnifies the effects of seismic waves. Structures in such areas can experience severe damage as shown in **Figure 9A.**

FIGURE 9 Earthquake Damage A magnitude-7.6 earthquake in northern Pakistan in 2005 destroyed mountain villages and killed more than 70,000 people.

FIGURE 10 Liquefaction and Landslides
A During a 1985 earthquake in Mexico, the soil beneath this toppled building liquified.
B A landslide triggered by an earthquake in 2001 buried this neighborhood in El Salvador.

Liquefaction

In areas where soil and rock are saturated with water, earthquakes can cause a process called **liquefaction.** When liquefaction occurs, what had been stable soil suddenly turns into liquid. The liquid cannot support buildings or other structures. Buildings and bridges may settle and collapse as shown in **Figure 10A.** Underground storage tanks and sewer lines may float toward the surface. During the 1989 Loma Prieta earthquake in San Francisco's Marina District, foundations failed and geysers of sand and water shot from the ground, indicating that liquefaction had occurred.

Landslides and Mudflows

Earthquakes can trigger different types of mass movement. These destructive events can quickly bury entire towns under millions of tons of debris.

Earthquakes often cause loose rock and soil on slopes to move. The result is a *landslide*, as shown in **Figure 10B.** Most landslides occur on steep slopes where sediment is loose or where the rocks are highly fractured. During the 1964 Alaska earthquake, much of the damage in the city of Anchorage was a result of landslides. Homes were lost when more than 200 acres of land slid toward the ocean.

In areas where the water content of soil is high, an earthquake can start a *mudflow*. During a mudflow, a mixture of soil and water slides rapidly downhill.

Reading Checkpoint *What is liquefaction?*

Major Earthquakes Since 1900

Year	Location	Magnitude†
1906	San Francisco, California	7.8
1923	Tokyo, Japan	7.9
1960	Southern Chile	9.5
1964	Alaska	9.2
1971	San Fernando, California	6.5
1985	Mexico City	8.1
1989	Loma Prieta, California	6.9
1994	Northridge, California	6.7
1999	Izmit, Turkey	7.4
1999	Chi Chi, Taiwan	7.6
2004	Indian Ocean near Indonesia	9.3
2005	Pakistan/Kashmir	7.6
2008	Sichuan, China	7.9
2010	Port-au-Prince, Haiti	7.0
2010	Maule, Chile	8.8
2011	Sendai, Japan	9.0

† Widely differing magnitudes have been estimated for some earthquakes. When available, moment magnitudes are used.

FIGURE 11 Indian Ocean Tsunami, 2004 A surge of water rushes inland as a tsunami strikes the coast of Thailand. On average, only one or two destructive tsunamis occur worldwide every year. Only about one tsunami in every 10 years causes major damage and loss of life.

Tsunamis A **tsunami** is a series of waves formed when the ocean floor shifts uddenly during an earthquake. For example, in 2004 a magnitude- 9.3 earthquake west of the island of Sumatra in the Indian Ocean produced devastating tsunamis. Without warning, huge waves such as the one shown in **Figure 11** struck coastal areas of Indonesia, Sri Lanka, Thailand, and several other countries killing over 230,000 people.

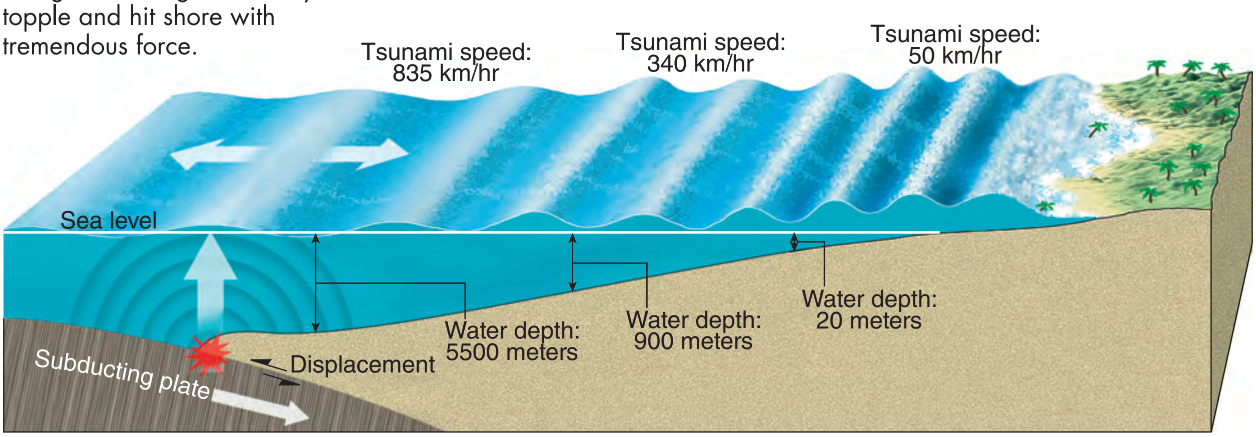
A tsunami can occur when an earthquake pushes up a slab of ocean floor along a fault. An underwater landslide or volcanic eruption can also trigger a tsunami. Once formed, a tsunami resembles the ripples created when you drop a pebble in a pond. Surprisingly, a tsunami on the open ocean is usually less than 1 meter high. This wave races across the ocean at hundreds of kilometers per hour. However, as the wave enters shallower water near shore, the wave slows down and water begins to pile up. As you can see in **Figure 12,** a tsunami can strike the shore as a huge wave that sweeps inland causing great destruction. Tsunamis range from a few meters to more than 30 meters high.

A tsunami warning system alerts people in coastal areas around the Pacific Ocean. After the deadly 2004 tsunami, a similar system was established for areas around the Indian ocean. A system is planned for the Atlantic Ocean. Scientists use devices that measure wave height to detect a tsunami. Tsunami warnings allow sufficient time to evacuate all but the area closest to the epicenter.

PLANET DIARY

For links about **Earthquakes,** visit PlanetDiary.com/HSES.

FIGURE 12 How a Tsunami Forms Movement of the ocean floor causes a tsunami. The speed of a tsunami is related to the ocean depth. As waves slow down in shallow water, they can grow in height until they topple and hit shore with tremendous force.



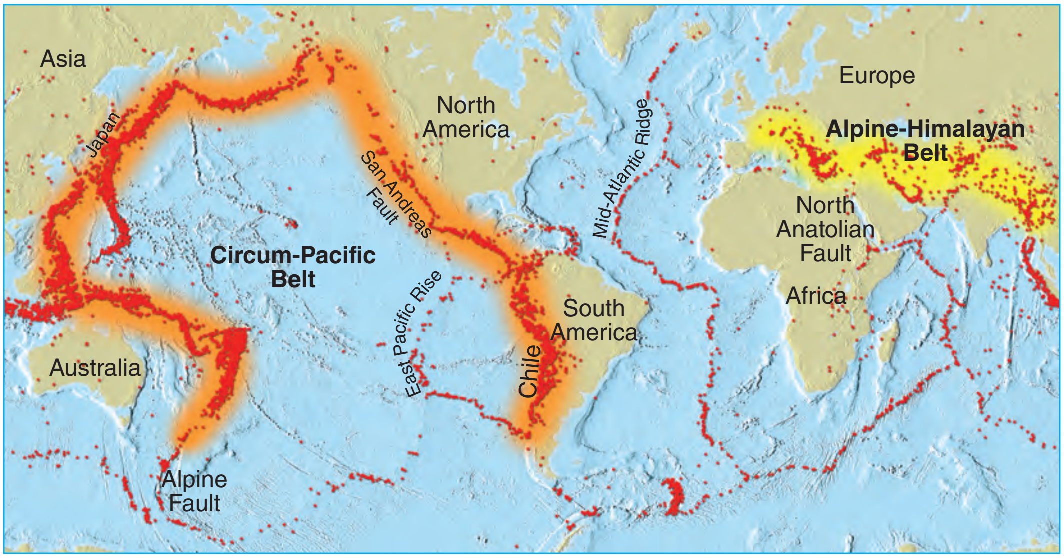


FIGURE 13 Earthquake Risk The map shows the distribution of nearly 15,000 earthquakes with magnitudes equal to or greater than 5 for a 10-year period. **Interpret Maps** *Where do you find most of the earthquakes—in the interiors of the continents or at the edges?*

Reducing Earthquake Damage

Earthquake damage depends on several factors. Two important factors are the strength and duration of seismic shaking and the materials and design of structures. **Earthquake damage and loss of life can be reduced by determining the earthquake risk for an area, building earthquake-resistant structures, and following earthquake safety precautions.**

Assessing Earthquake Risk How can people reduce damage from earthquakes? First, it is important to know the risk of earthquakes in a region. As you can see in **Figure 13,** the distribution of earthquakes forms a pattern. Scientists have found that earthquakes are most frequent along the boundaries of Earth's tectonic plates.

Scientists use several methods to determine earthquake risk. They study historical records of earthquakes. They use devices to measure uplift, subsidence, and strain in the rocks near active faults. They also study "seismic gaps." A **seismic gap** is an area along a fault where there has not been any earthquake activity for a long period of time. Scientists hypothesize that the buildup of strain along a seismic gap will eventually lead to an earthquake. Considering all these data, scientists are studying ways to estimate the probability that an earthquake will occur in an area within the next 30 to 100 years.

Scientists also look for warning signs that an earthquake is about to strike. In addition to monitoring fault movements, they measure water levels and pressure in wells, radon gas emissions, and changes in the electromagnetic properties of rocks. But efforts at short-term prediction of earthquakes have not generally been successful.

Reading Checkpoint *How do scientists assess earthquake risk?*

FIGURE 14 **Cross Braces**
Strong, diagonal beams called cross-braces have been installed in this building to improve the structure's ability to withstand seismic waves.

Seismic-Safe Design Many cities in earthquake-prone regions have building codes that set standards for earthquake-resistant structures. Steel frames can be reinforced with cross-braces as shown in **Figure 14.** Buildings can be mounted on large rubber and steel pads, called base-isolators, which absorb the energy of seismic waves. Wood-frame homes can be reinforced and bolted to their foundations. People can "retrofit" or reinforce older buildings to make them more earthquake resistant.

Utility lines must also be protected. To prevent fi es or explosions in gas mains, flexible pipes and automatic shut-off v lves can be installed. Flexible joints in water mains can prevent loss of water pressure needed to fi ht fi es. Much of the damage after the 1906 San Francisco earthquake resulted from fi es. The fi es could not be put out because water mains had broken.

Earthquake Safety Knowing what to do during an earthquake can reduce your risk of injury. The basic rule is to "drop, cover, and hold." Indoors, crouch beneath a sturdy table or desk and hold onto it. If no desk or table is nearby, crouch against an inner wall away from the outside of a building. Cover your head and neck with your arms. Avoid windows, mirrors, and furniture that might topple.

If you are outdoors when an earthquake strikes, move to an open area. Avoid vehicles, power lines, trees, and buildings. Sit down to avoid being thrown down. The danger does not end once an earthquake has stopped because an aftershock could cause weakened structures to collapse.

8.3 Assessment

Review Key Concepts

1. Describe five hazards caused by earthquakes.

2. Explain how earthquake-related damage can be reduced.

3. What is a tsunami?

4. What is a seismic gap?

Think Critically

5. **Predict** In an earthquake-prone area, it has been many years since the last earthquake along a fault. Should residents be concerned about a future earthquake? Explain.

6. **Propose a Solution** A builder in Alaska has a choice of two sites for a building: one is on filled land next to the ocean, and the other is inland on solid ground. Both sites are the same distance from an active fault. Which site should the builder choose? Explain.

7. **Explain** Why is it possible to issue a tsunami warning but not provide a warning for an earthquake? Describe a scenario where a tsunami warning would be of little value.

BIGIDEA DYNAMIC EARTH

8. **Predict** In Lesson 8.1, you learned about the elastic energy stored in rocks before an earthquake and the elastic rebound hypothesis. How could this information be used to try to predict earthquakes?

8.4 Earth's Layered Structure

COMPARED TO THE planets we see in the night sky, Earth's interior is close by. But we can't reach it. The deepest well has drilled only 12 kilometers into Earth's crust. With such limited access, how do we know what Earth's interior is like? Most knowledge of the interior comes from the study of seismic waves that travel through Earth.

Layers Defined by Composition

If Earth's materials had the same chemical composition, or makeup, throughout seismic waves would travel in straight lines at constant speed. However, this is not the case. Seismic waves reaching seismographs located farther from an earthquake travel at faster average speeds than those recorded at locations closer to the event. As the speed of seismic waves increase, the waves *refract*, or bend as shown in **Figure 15.** Scientists study the speed and paths of seismic waves to determine the chemical composition of rocks inside Earth. Scientists used this information to defi e layers of Earth. **Earth's interior consists of three major layers defi ed by their chemical composition—the crust, mantle, and core.**

Crust The **crust**—the thin, rocky outer layer of Earth—is divided into oceanic and continental crust. The oceanic crust is roughly 7 kilometers thick and composed of the igneous rocks basalt and gabbro. The continental crust is 8–75 kilometers thick, but averages a thickness of 40 kilometers. It consists of many rock types, but the most common rock found there is a granitic rock called granodiorite. The rocks of the continental crust have an average density of about 2.7 g/cm^3 and some are over 4 billion years old. The rocks of the oceanic crust are younger (180 million years or less) and have an average density of about 3.0 g/cm^3.

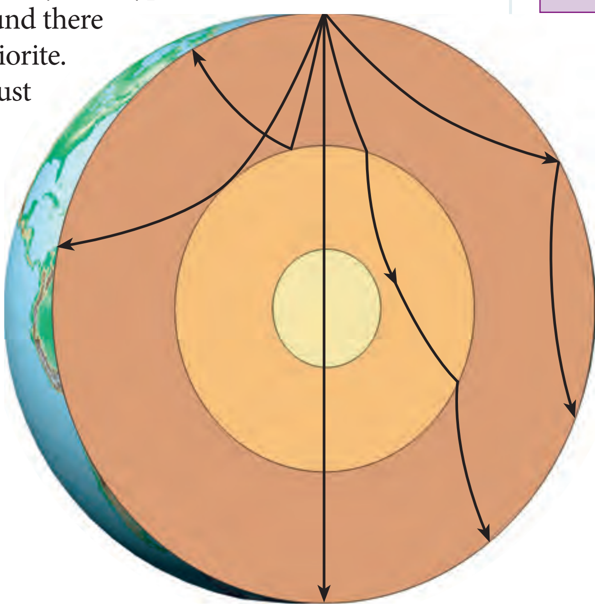


FIGURE 15 Paths of Seismic Waves The arrows show a few possible paths that seismic waves may travel. **Infer** *What causes the wave paths to change?*

Key Questions

What are Earth's layers based on chemical composition?

What are Earth's layers based on physical properties?

How did scientists determine Earth's structure and composition?

Vocabulary

- crust • mantle
- lithosphere
- asthenosphere
- outer core • inner core
- Moho

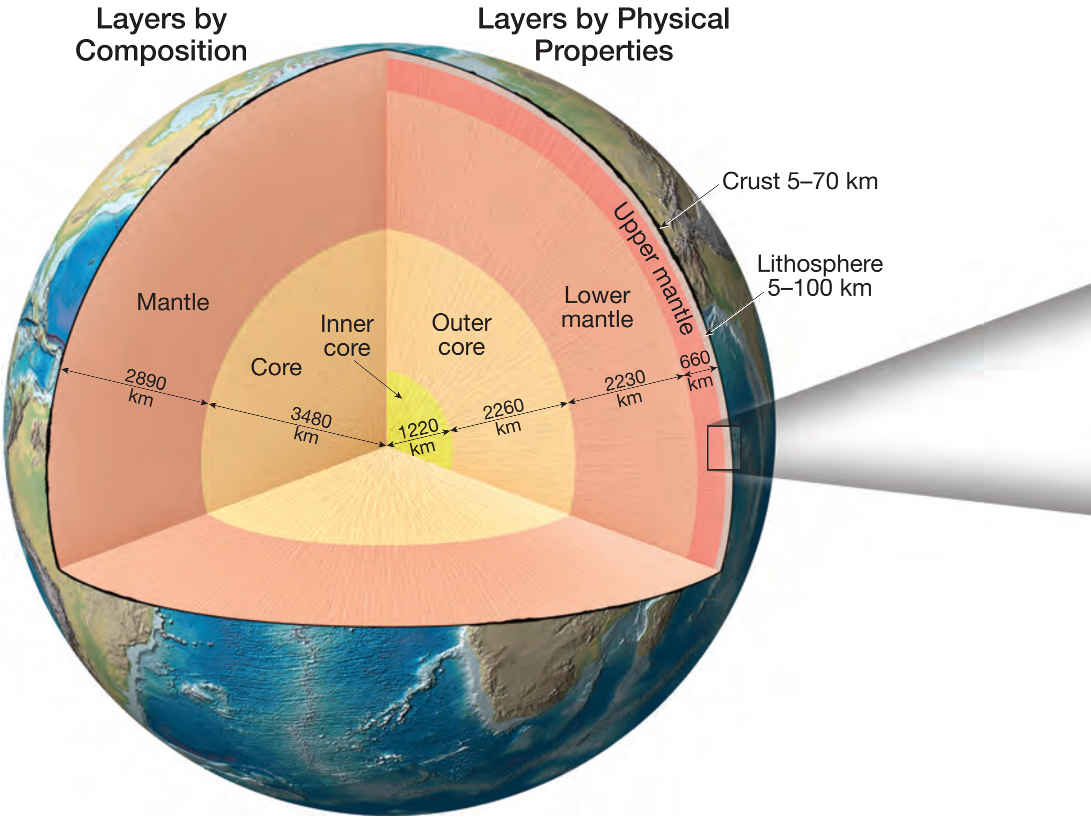
Reading Strategy

Sequence Copy the flowchart. After you read, complete the sequence of Earth's layers defined by physical properties.

Earth's Internal Structure

Lithosphere
↓
a. ?
↓
b. ?
↓
Outer core
↓
c. ?

FIGURE 16 Earth's Layered Structure Based on chemical composition, Earth is made up of the crust, mantle, and core. Based on physical properties, Earth is made up of the lithosphere, asthenosphere, lower mantle, outer core, and inner core. The block diagram shows the relationship between the crust, lithosphere, and asthenosphere.
Infer ***Which part of Earth has the highest density? Explain.***



Mantle Over 82 percent of Earth's volume is contained in the **mantle**—a solid, rocky shell that extends to a depth of 2890 kilometers. The boundary between the crust and mantle represents a change in chemical composition. A common rock type in the uppermost mantle is peridotite, which has a density of 3.4 g/cm^3.

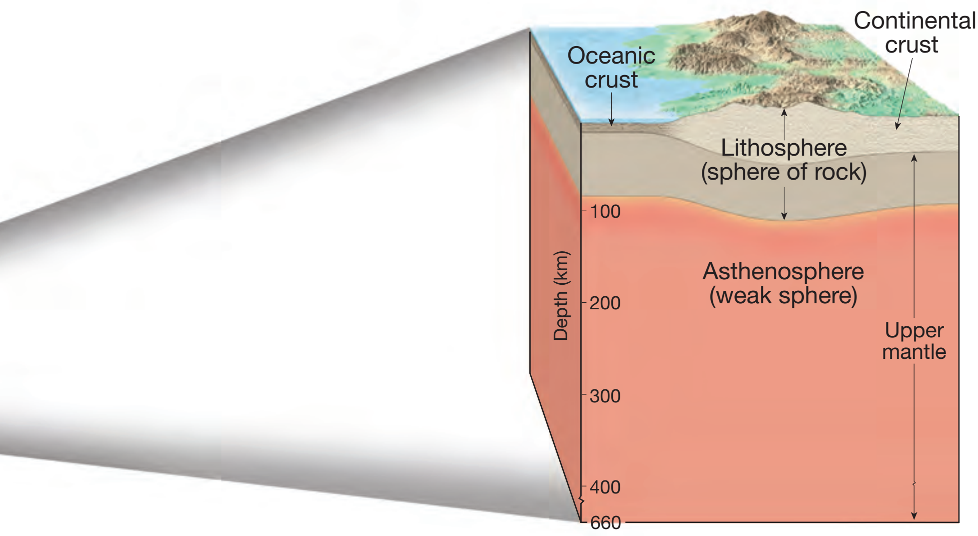
Core The core is a sphere composed mostly of an iron-nickel alloy. At the extreme pressures found in the center of the core, the average density of the iron-rich material is 13 g/cm^3 (13 times denser than water). **Figure 16** shows Earth's layered structure.

Layers Defined by Physical Properties

The physical properties of temperature, pressure, and density increase with depth in Earth. When a substance is heated, the transfer of energy increases the vibrations of particles. If the temperature exceeds the melting point, the forces between particles are overcome and melting begins.

If temperature were the only factor that determined whether a substance melted, our planet would be a molten ball covered with a thin, solid outer shell. Fortunately, pressure also increases with depth and increases rock strength. Depending on the temperature and pressure of the physical environment, rock may behave like a brittle solid, a putty, or a liquid. **Earth can be divided into layers based on physical properties—the lithosphere, the asthenosphere, lower mantle, the outer core, and the inner core.**

Lithosphere and Asthenosphere



Lithosphere Earth's outermost layer consists of the crust and uppermost mantle and forms a relatively cool, rigid shell called the **lithosphere.** This layer averages about 100 kilometers in thickness as shown in Figure 16.

Athenosphere Beneath the lithosphere lies a soft, comparatively weak layer known as the **asthenosphere.** Within the asthenosphere, the rocks are close enough to their melting temperatures that they are easily deformed. Thus, the asthenosphere is weak because it is near its melting point, just as hot wax is weaker than cold wax. The lower lithosphere and asthenosphere are both part of the upper mantle.

Lower Mantle From a depth of about 660 kilometers down to near the base of the mantle lies a more rigid layer called the lower mantle. Despite their strength, the rocks of the lower mantle are still very hot and capable of gradual flow.

Inner and Outer Core The core, which is composed mostly of an iron-nickel alloy, is divided into two regions with different physical properties. The **outer core** is a liquid layer 2260 kilometers thick. The flow of metallic iron within this layer generates Earth's magnetic field. Just as there is a magnetic field around a bar magnet, an immense magnetic field surrounds Earth, as shown in **Figure 17.** The poles of the magnetized needle on a compass align themselves with Earth's magnetic field.

The **inner core** is a sphere having a radius of 1220 kilometers. Despite its higher temperatures, the materials in the inner core are compressed into a solid state by the immense pressure.

Reading Checkpoint *Why is the inner core solid?*

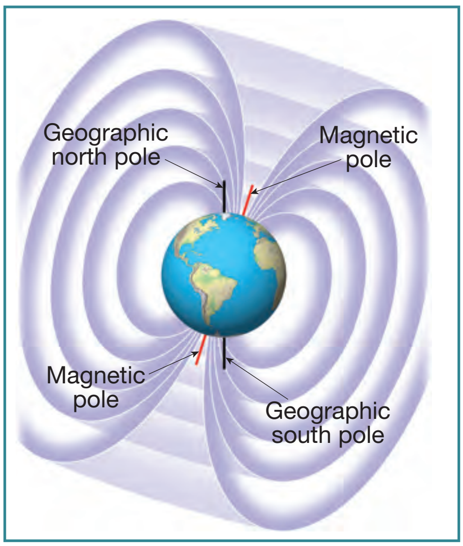


FIGURE 17 Earth's Magnetic Field Movements in Earth's liquid outer core produce the planet's magnetic field. As a result, a compass needle points to one of the magnetic poles.

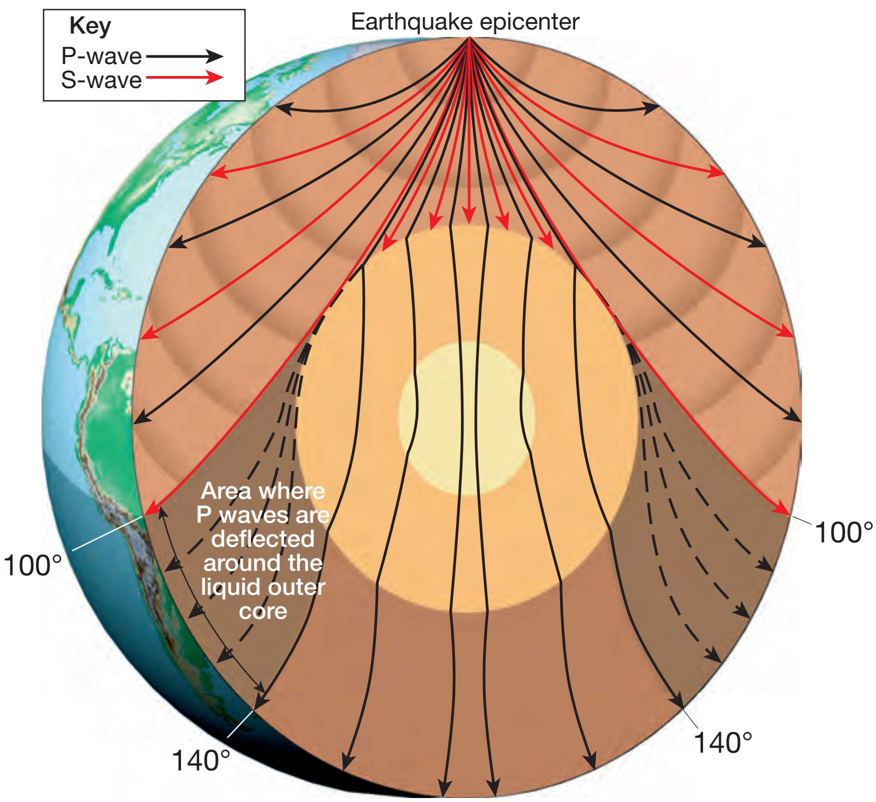
Discovering Earth's Layers

Recall that seismic waves bend as they travel through Earth and that this information helped scientists to infer the planet's layered structure. **During the twentieth century, studies of the paths of P and S waves through Earth helped scientists identify the boundaries of Earth's layers and determine that the outer core is liquid.**

In 1909, a Croatian seismologist, Andrija Mohorovičić, presented the fi st evidence of layering within Earth's mantle. By studying seismic records, he found that the velocity of seismic waves increased abruptly about 50 kilometers below eastern Europe. This boundary separates the crust from the underlying mantle and is now known as the Mohorovičić discontinuity. The name of the boundary is usually shortened to **Moho.**

Another boundary had been discovered in 1906 between the mantle and outer core. Seismic waves from even small earthquakes can travel around the world. This is why a seismograph in Antarctica can record earthquakes in California or Italy. However, it was observed that P waves bend around the liquid outer core beyond about 100 degrees away from an earthquake's epicenter. This region, where bent P waves arrive, is sometimes called the *shadow zone*. You can see the shadow zone in **Figure 18.** It is the area of Earth from approximately 100 degrees to 140 degrees from the earthquake's epicenter. The outer core also causes P waves that travel through the core to arrive several minutes later than expected.

FIGURE 18 Earth's Interior Showing P and S Wave Paths
P waves either bend around or travel through the liquid outer core while S waves stop at the mantle-core boundary.



The reason the wave paths bend is due to the differences in the composition of the core and the overlying mantle. The P waves bend around the core in a way similar to how sound waves bend around the corner of a building. For example, you can hear people talking around a corner even though you cannot see them. In this way, rather than stopping in the shadow zone, P waves bend around the outer core. It was further shown that S waves could not travel through the outer core. Therefore, geologists concluded that this layer is liquid.

Discovering Earth's Composition

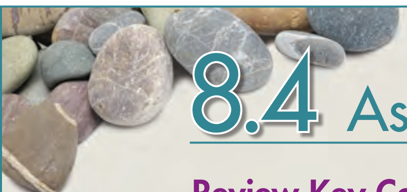
To determine the composition of Earth's layers, scientists studied seismic data and rock samples from the crust, mantle, and meteorites. They also performed high-pressure experiments on Earth materials. Scientists obtain data on the seismic properties of rocks by performing experiments at high pressures. Small samples of rock and metal are squeezed and heated to the same conditions found in Earth's deep interior. Scientists then measure the speeds of P and S waves through the samples.

Seismic data and rock samples from drilling indicate that the continental crust is mostly made of low-density granitic rocks. Until the late 1960s, scientists had only seismic evidence they could use to determine the composition of oceanic crust. The development of deep-sea drilling technology made it possible to obtain rock samples from the ocean floor. The crust of the ocean floor has a basaltic composition.

The composition of the rocks of the mantle and core is known from more indirect data. Some of the lava that reaches Earth's surface comes from the partially melted asthenosphere within the mantle. In the laboratory, experiments show that partially melting the rock called peridotite produces a substance that is similar to the lava that erupts during volcanic activity of islands such as Hawaii.

Surprisingly, meteorites that collide with Earth provide evidence of Earth's inner composition. Meteorites are assumed to be composed of the original material from which Earth was formed. Their composition ranges from metallic meteorites made of iron and nickel to stony meteorites composed of dense rock similar to peridotite. Because Earth's crust contains a smaller percentage of iron than do meteorites, geologists believe that dense metals, such as iron, sank toward Earth's center during the planet's formation.

Reading Checkpoint *Why did scientists conduct experiments at high-pressures to learn about the seismic properties of rocks?*



8.4 Assessment

Review Key Concepts

1. Describe Earth's layers based on composition.
2. List Earth's layers based on physical properties, and their characteristics, in order from Earth's center to the surface.
3. What evidence led scientists to conclude that Earth's outer core is liquid? Explain.

Think Critically

4. **Compare and Contrast** Compare the physical properties of the asthenosphere and the lithosphere.
5. **Infer** Why are meteorites considered important clues to the composition of Earth's interior?

WRITING IN SCIENCE

6. **Creative Writing** Write a short fictional story about a trip to Earth's core. Make sure the details about the layers of Earth's interior are scientifically accurate.

Effects of Earthquakes

As Earth's asthenosphere sluggishly flows, the overlying tectonic plates of the lithosphere are dragged along with it. Sometimes these tectonic plates collide head-on, while at other times they grind past one another. No matter how the tectonic plates collide, very strong forces build up between them as they are propelled by the motion of the asthenosphere. These forces get larger and larger until suddenly, the plates shift their positions. This releases a shock wave of energy that travels through Earth, causing ground shaking and deformation. This is called an **earthquake.** Most earthquakes last less than one minute. Even so, the effects of an earthquake can be devastating and long-lasting.

TSUNAMI ▶
In 1755, an earthquake in Lisbon, Portugal, caused a tsunami, as illustrated in this painting. A **tsunami** is a huge sea wave that is set off by an undersea earthquake or volcanic eruption. When tsunamis break on shore, they often devastate coastal areas. Tsunamis can race at speeds of about 720 km/h (450 mph) and may reach heights of about 30.5 meters (100 feet).

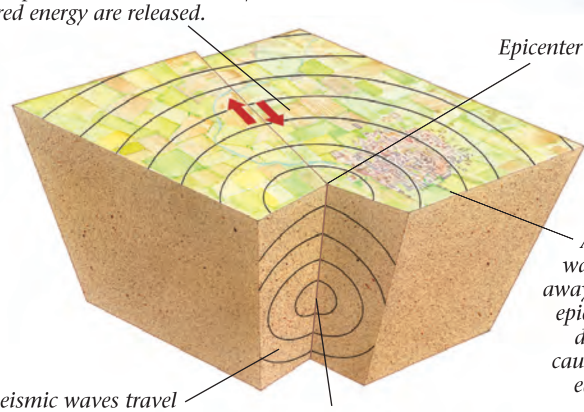
THE BIG ONE
On December 26, 2004, a massive undersea earthquake struck Indonesia, caused by the unprecedented rupture of a 1500 kilometer (900 mile) long fault zone in Earth's crust. The tsunami produced by this earthquake inundated coastlines around the Indian Ocean and killed over 230,000 people in 14 countries, making this event one of the deadliest natural disasters in modern history.

LANDSLIDE
In January 2001, an earthquake struck El Salvador. It caused the landslide that left these Salvadoran women homeless. A **landslide** is a sudden drop of a mass of land down a mountainside or hillside. Emergency relief workers from around the world often rush to the site of an earthquake disaster like the one that occurred in El Salvador. ▼

▲ **INFRASTRUCTURE DAMAGE**
When an earthquake occurred in Los Angeles in 1994, underground gas and water lines burst, causing fires and floods. Earthquakes often cause tremendous damage to the **infrastructure**—the network of services that supports a community. Infrastructure includes power utilities, water supplies, and transportation and communication facilities.

AVALANCHE ▶
Earthquakes may trigger an **avalanche**—a sudden fall of a mass of ice and snow. In 1970, a severe earthquake off the coast of Peru caused a disastrous slide of snow and rock that killed some 18,000 people in the valley below.

▲ **WHEN THE EARTH CRACKS**
Most people killed or injured by an earthquake are hit by debris from buildings. Additional damage can be caused by **aftershocks**—tremors that can occur hours, days, or even months after an earthquake. The scene above shows the city of Anchorage, Alaska, after a major earthquake in 1964. Extensive ground tremors caused the street to break up as the soil below it collapsed. Buildings and cars were dropped more than 10 feet (3 m) below street level.



▲ **SEISMIC WAVES**
As tectonic forces build, rocks on both sides of the fault deform in response, and stress levels increase. The fault ruptures when the tectonic forces overcome the forces holding the rocks together along the fault. The tectonic plates suddenly move, causing **seismic waves** to travel through the ground. The waves travel outward from an underground area called the focus, or hypocenter. Damage is usually greatest near the **epicenter**, the point on the surface directly above the focus.

Assessment

1. **Key Terms** Define **(a)** earthquake, **(b)** tsunami, **(c)** landslide, **(d)** infrastructure, **(e)** avalanche, **(f)** aftershock, **(g)** seismic wave, **(h)** epicenter.
2. **Physical Processes** Explain how the buildup of tectonic forces along faults causes earthquakes.
3. **Environmental Change** List and describe the types of damage a region may suffer if it experiences an earthquake.
4. **Natural Hazards** How does an earthquake damage the services that communities need to survive?
5. **Critical Thinking** **Solve Problems** What can a community do to reduce the amount of earthquake damage that might occur in the future?

INQUIRY
EXPLORATION LAB

Locating an Earthquake

Problem How can you determine the location of an earthquake's epicenter?

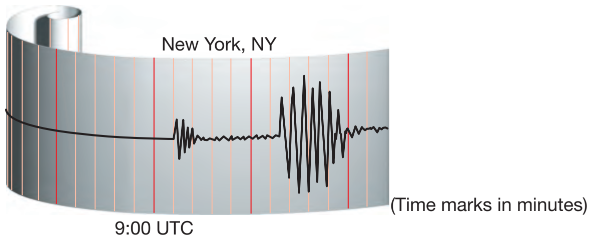
Materials pencil, drawing compass, world map or atlas, photocopy of the map on next page

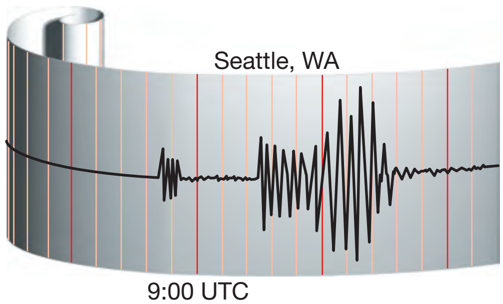
Skills Measure, Interpret Maps, Interpret Graphs

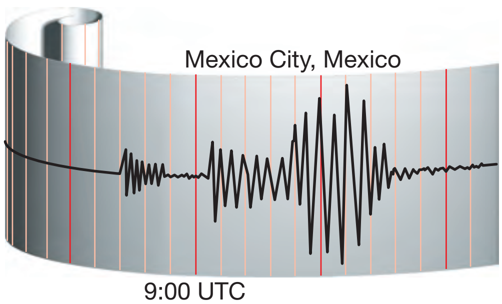
Connect to the Big idea To locate an epicenter, records from three different seismographs are needed. Ideally, this activity should be done using a globe. When projected onto a flat map, the circles showing distances to the epicenter become distorted. For this reason, the method used here is an approximation.

Procedure

1. These three seismograms recorded the same earthquake, in New York City, Seattle, and Mexico City. Use the travel-time graph to determine the distance that each station is from the epicenter. Record your answers in a data table like the one shown.
2. Refer to a world map or atlas for the locations of the three seismic stations. Place a small dot showing the location of each of the three stations on the photocopy of the map on the next page. Neatly label each city on the map.



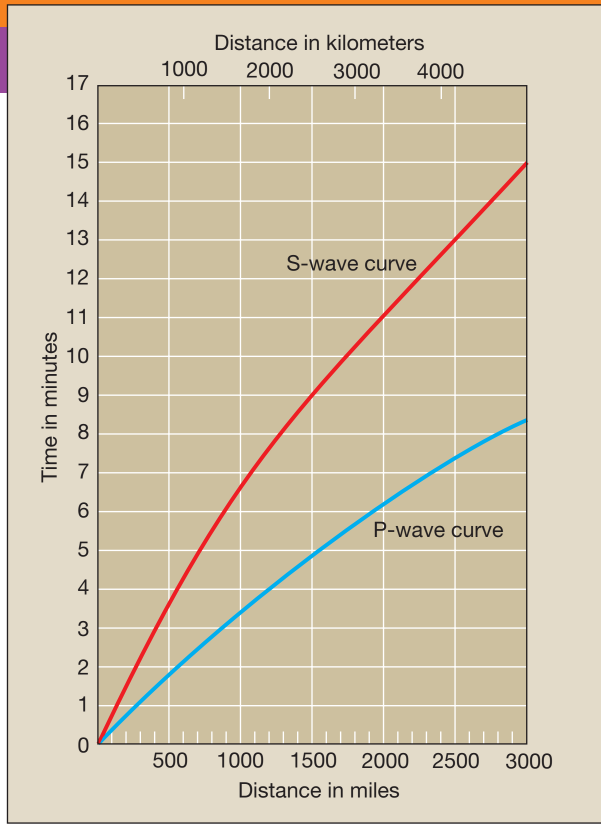




Data Table

	New York	Seattle	Mexico City
Elapsed time between first P and first S waves			
Distance from epicenter in miles			

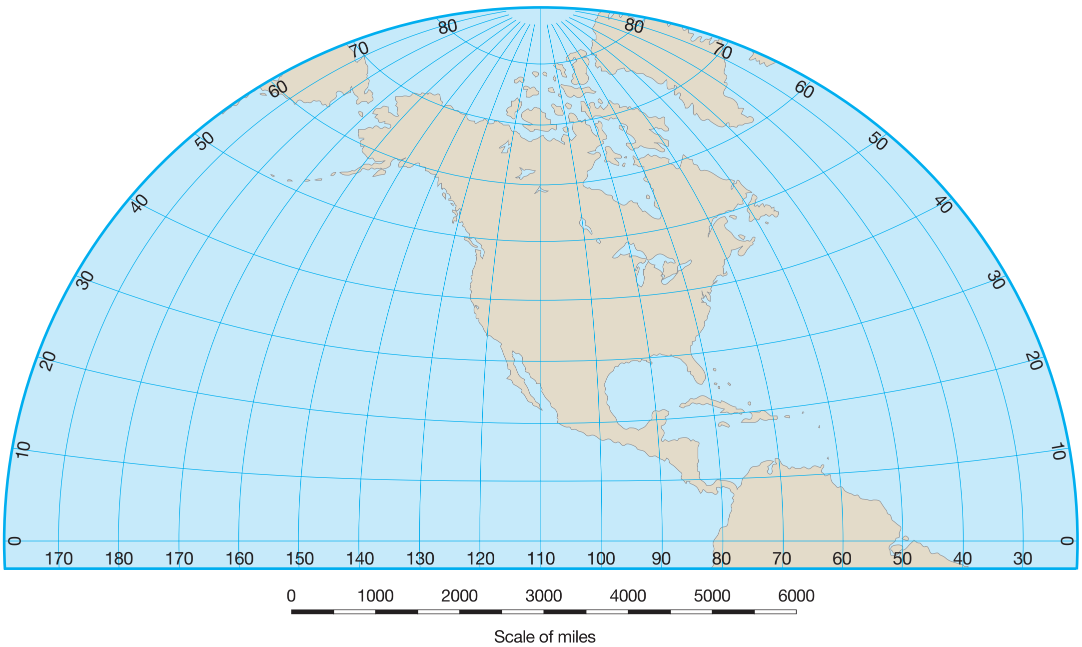
3. On the map, use a drawing compass to draw a circle around each of the three stations. The radius of the circle, in miles, should be equal to each station's distance from the epicenter. Use the scale on the map to set the distance on the drawing compass for each station.
Ca u t io n: *Use care when handling the drawing compass.*



Analyze and Conclude

1. **Interpret Graphs** How far from the epicenter are the three cities located?
2. **Calculate** What would the distances from the epicenter to the cities be in kilometers?
3. **Interpret Maps** What is the approximate latitude and longitude of the epicenter of the earthquake that was recorded by the three stations?
4. **Draw Conclusions** On the New York seismogram the first P wave was recorded at 9:01 UTC. UTC is the international standard on which most countries base their time. At what time (UTC) did the earthquake actually occur? Explain.

GO FURTHER Use the Internet or the library to fi d the locations of recent earthquake epicenters. Make a data table displaying the location, date, and magnitude of ten recent earthquakes. Report your fi dings to the class.



ES.1 The student will plan and conduct investigations in which **d.** maps and globes are read and interpreted, including location by latitude and longitude. Also covered: **ES.1.a, ES.1.c, ES.2.c**

8 Study Guide

Big idea Dynamic Earth

8.1 What Is an Earthquake?

Faults are fractures in Earth along where movement has occurred.

According to the elastic rebound hypothesis, most earthquakes are produced by the rapid release of energy stored in rock that has been subjected to great forces. When the strength of the rock is exceeded, it suddenly breaks, releasing some of its stored energy as seismic waves.

earthquake (218)
fault (218)
focus (218)
seismic waves (218)
epicenter (218)
elastic rebound (220)
aftershock (221)

8.2 Measuring Earthquakes

Earthquakes produce two main types of seismic waves—body waves and surface waves.

An instrument that records seismic waves is called the seismograph.

The Richter scale and the moment magnitude scale measure earthquake magnitude. The Modified Mercalli scale is based on earthquake intensity.

You can use a travel-time graph, data from seismograms at three or more locations, and a globe to determine an earthquake's epicenter.

P wave (222)
S wave (222)
surface wave (223)
seismograph (224)
seismogram (224)
moment magnitude (225)

8.3 Earthquake Hazards

Earthquake-related hazards include: seismic shaking, liquefaction, landslides and mudflows, and tsunamis.

Earthquake damage and loss of life can be reduced by determining the earthquake risk for an area, building earthquake-resistant structures, and following earthquake safety precautions.

liquefaction (229)
tsunami (230)
seismic gap (231)

8.4 Earth's Layered Structure

Earth's interior consists of three major layers defined by their chemical composition—the crust, the mantle, and the core.

Earth can be divided into layers based on physical properties—the lithosphere, the asthenosphere, lower mantle, the outer core, and the inner core.

During the twentieth century, studies of the paths of P waves and S waves through Earth helped scientists establish the boundaries of Earth's layers and determine that the outer core is liquid.

To determine the composition of Earth's layers, scientists studied seismic data and rock samples from the crust, mantle, and meteorites. They also performed high-pressure experiments on Earth materials.

crust (233)
mantle (234)
lithosphere (235)
asthenosphere (235)
outer core (235)
inner core (235)
Moho (236)

8 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. Approximately how many earthquakes are strong enough to be felt each year worldwide?
   a. 500 **c.** 10,000
   b. 1000 **d.** 30,000

2. What is the location on the surface directly above the earthquake focus called?
   a. epicenter **c.** magnitude
   b. fault **d.** Moho

3. The rigid layer of Earth that includes the entire crust and the uppermost part of the mantle is called the
   a. asthenosphere. **c.** lithosphere.
   b. mesosphere. **d.** Moho.

4. The instrument that records earthquakes is called
   a. a seismogram. **c.** seismology.
   b. a seismologist. **d.** a seismograph.

5. Look at the map of earthquake activity in Lesson 3. Which region has the most earthquake activity?
   a. central Europe
   b. the edge of the Pacific Ocean
   c. eastern North America
   d. central Africa

6. What material do scientists believe makes up a large part of the upper mantle?
   a. basalt **c.** iron
   b. granite **d.** peridotite

7. The point at which an earthquake begins is called
   a. a foreshock. **c.** the focus.
   b. the epicenter. **d.** the Moho.

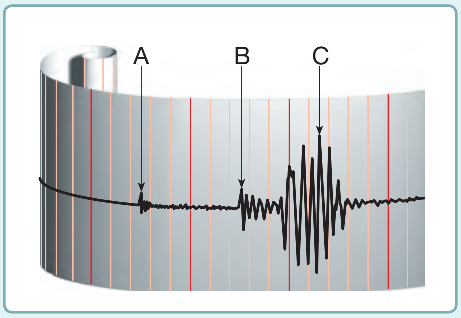
8. In areas where soil is saturated with water, earthquakes can turn stable soil into a fluid during a process called
   a. faulting. **c.** tsunamis.
   b. liquefaction. **d.** subsidence.

9. To fi d the epicenter of an earthquake, what is the minimum number of seismic stations that are needed?
   a. three **c.** five
   b. nine **d.** two

10. What scale do scientists today most often use to express the magnitude of an earthquake?
    a. Richter scale **c.** tsunami scale
    b. moment magnitude **d.** Moho scale

Understand Concepts

Use the diagram below to answer Questions 11 and 12.



11. The diagram shows a typical recording of an earthquake. What is the record called?
12. Identify the waves recorded at A, B, and C on the diagram.
13. What is the elastic rebound hypothesis?
14. What type of seismic wave causes the greatest destruction to buildings?
15. In addition to the damage caused directly by seismic shaking, list four other types of destructive events that can be triggered by earthquakes.
16. Describe the composition and physical properties of the crust.
17. What is liquefaction and how can earthquakes cause liquefaction to occur?
18. List the major differences between P waves and S waves.
19. How much more ground shaking occurs in an earthquake that measures 4.2 on the Richter scale compared with an earthquake that measures 6.2 on the Richter scale?

20. What are two factors that can determine the amount of destruction that results from an earthquake?

Think Critically

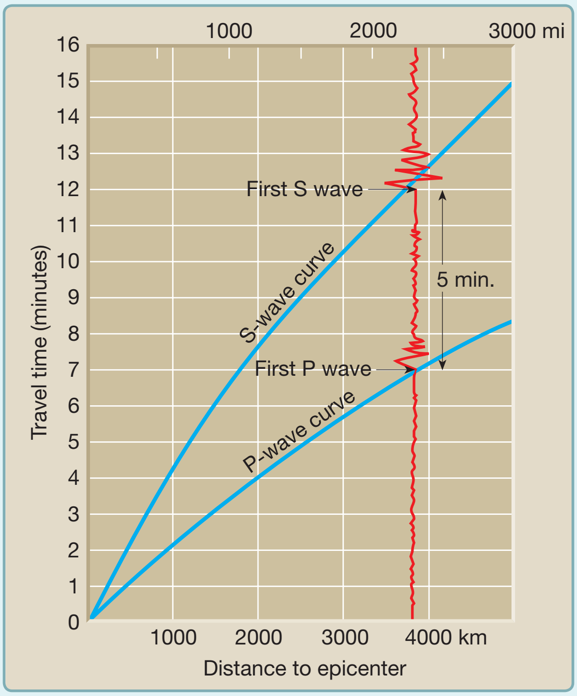
21. **Apply Concepts** Give two reasons why an earthquake with a moderate magnitude might cause more extensive damage than an earthquake with a high magnitude.

22. **Compare and Contrast** How are the moment magnitude scale and the Richter scale different?

23. **Infer** How did scientists determine the structure and composition of Earth's interior?

Analyze Data

Use the diagram below to answer Questions 24–26.



24. **Interpret Graphs** Determine the distance between an earthquake and seismic station if the fi st S wave arrives three minutes after the fi st P wave.

25. **Interpret Graphs** If a seismic station is 2500 kilometers from the earthquake's epicenter, approximately when will the fi st P wave be received? When will the fi st S wave be received?

26. **Calculate** What is the difference in the travel-times of the fi st P wave and the fi st S wave if the seismic station is 1000 kilometers from the earthquake epicenter?

Concepts in Action

27. **Apply Concepts** Why is the moment magnitude the most commonly used scale by scientists for measuring earthquakes?

28. **Relate Cause and Effect** Describe a tsunami from the event that produces it to the time that it reaches a coastline.

29. **Infer** A magnitude 6 earthquake has an intensity of V on the Mercalli scale 10 km from the epicenter. But the same earthquake has an intensity of VII on the Mercalli scale 25 km from the epicenter. What might explain this difference?

30. **Writing in Science** Research a recent earthquake and write about the earthquake damage in the style of a newspaper article.

Performance-Based Assessment

31. **Design an Experiment** Design a model seismograph to record simulated earthquakes. When your model is completed, test it for the class. Then determine how your seismograph design could be improved or changed if it doesn't work well.

Virginia SOL Test Prep

Tips for Success

Narrowing the Choices If, after reading all the answer choices, you are not sure which one is correct, eliminate those answers that you know are wrong. In the question below, first eliminate the choices you know are wrong. For example, answer choice C can be eliminated because the asthenophere, although it is solid, is not cool. Then focus on the remaining choices.

Which answer *best* describes the characteristics of the asthenosphere?

A liquid and metallic
B extremely hot but solid
C cool and solid
D solid but weak and able to flow slowly

(Answer: D)

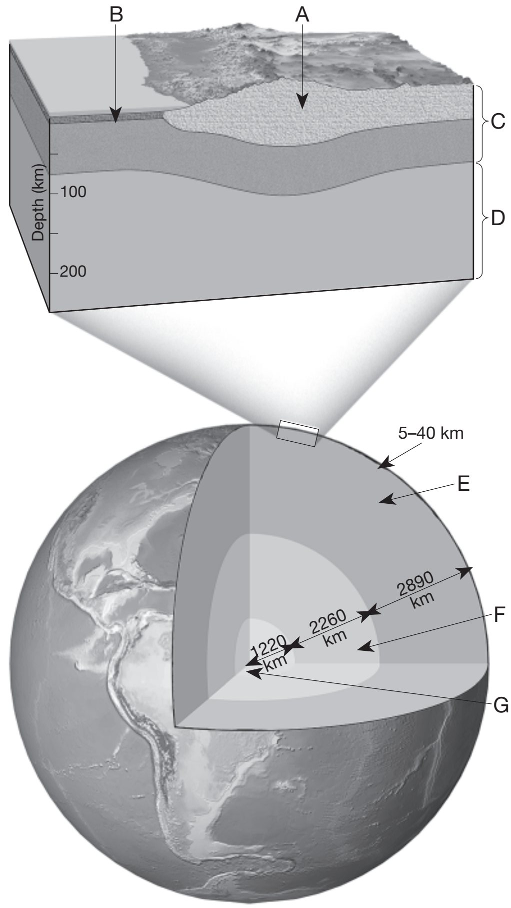
Choose the letter that best answers the question.

1 What property that is different for P and S waves provides a method for locating the epicenter of an earthquake?
A magnitude
B foci
C modes of travel
D speed
ES.7.b

2 Movements that follow a major earthquake often generate smaller earthquakes called—
F aftershocks
G foreshocks
H surface waves
J landslides
ES.7.b

3 An earthquake in the ocean floor can cause a destructive sea wave called a—
A P wave
B S wave
C Moho
D tsunami
ES.7.b

Use the diagram below to answer Question 4.



4 In the diagram, which letters would indicate layers that form the lithosphere?
F A, B, C
G C, D, E
H D, E
J F, G
ES.7.b

If You Have Trouble With . . .				
Question	1	2	3	4
See Lesson	8.2	8.1	8.3	8.4